HIGH-EFFICIENCY EMITTER-WRAP-THROUGH CELLS

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ABSTRACT: In order to further decrease cost of solar electricity cheaper silicon wafers with low bulk diffusion length have to be used. These wafers are a challenge for adapted cell concepts since the diffusion length can even fall short of the cell thickness and therefore strongly reduce the short-circuit current in standard cells. The emitter-wrap-through (EWT) concept is very suitable for material with a diffusion length below the cell thickness as will be demonstrated in this paper. In contrast to the rear-contacted cell (RCC) that will also be treated in this article, the front emitter is contacted through via-holes and contributes very efficiently to the overall current collection. By this mechanism, the EWT performance becomes nearly independent of the bulk diffusion length as will be demonstrated by fabricated EWT and RCC on degrading Czochralski material. Measuring the respective cells on the same wafer at different degradation states is a very elegant way to get informations about the cell performances for different diffusion lengths. These measurements match exactly the predictions from our 2D simulations.
Keywords: High-Efficiency – 1: Degradation – 2: Medium quality substrates – 3

1 INTRODUCTION

The emitter-wrap-through (EWT) cell [1] is a cell concept which is very well adapted to base material with lower bulk diffusion length. Thus, it is under investigation in several research groups [1-6]. It competes with the rear-contacted cell (RCC) that is somewhat easier to process but lacks the EWT specific emitter via-holes. In this article, both concepts are presented and compared. There will also be a summary of the different cell variants processed recently at Fraunhofer ISE. Finally, the cell performances on degrading Czochralski (Cz) material will be investigated by measuring RCC and EWT cells processed on the same wafer at different degradation states i.e. bulk diffusion lengths L_{bulk}. This is a very elegant and fast way to determine the EWT advantage for a broad range of L_{bulk}.

2 SINGLE-SIDE CONTACT CELL CONCEPTS

The EWT cell concept with realized 21.4% efficiency at Fraunhofer ISE [7] is shown upside down in Fig. 1. Both n- and p-grids are on the backside and contact resistance is reduced by a boron LBSF as well as by a selective emitter. The emitter covers the entire front side, the surface of the via holes and the rear side except the small base regions.

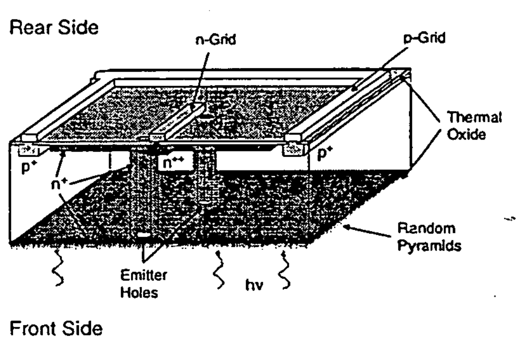

Fig. 1: High-efficiency EWT cell structure

The front surface is covered by a random pyramids texture in order to reduce reflexion. Passivation is carried out by a thermally grown AR oxide on front and back surfaces.

The only difference between RCC and EWT is that the RCC lacks the via holes that connect the front and rear emitter. This is why the RCC's front emitter is floating and serves more to passivate the surface than to carrier collection.

There are several advantages of RCC and EWT over most two-side metallized cells. Since both busbars are on the backside, the series interconnection in a module is much simplified and can be realized by preparing a suitable electrical circuit on the module back side and then simply putting the cells in the solder. The fact that the entire metallization is on the back side omits additionally all shading on the front side which increases J_{sc} obviously.

With reasonable grid width, the cells can also be illuminated bifacially. The loss in J_{sc} due to the lack of a fully metallized back side is negligible as has been demonstrated by our cells and the results will be presented below. The absence of metal on the front side leads to a very homogeneous and esthetic module appearance that can be *just black* if a suitable module background foil is used. This can be especially interesting for architectural reasons.

Also there is a broad range of different EWT/RCC variants possible – from high-efficiency to quite simple industrial processes. But the most striking advantage of the EWT concept is the front and back emitter connection through the via holes that is responsible for a very efficient current collection. By this mechanism the EWT cell performance is – over a wide range – nearly independent of the cell thickness W to L_{bulk} ratio.

3 COMPARISON OF EWT VS. RCC

Before processing the different cell types, 2D simulations using DESSIS [8] and PVObjects [9] have been carried out [5]. In order to determine the benefit of the EWT concept for industrial cells compared to laboratory cells, two simulation parameter sets have been used: „high-η" and „industrial". The former contains high-efficiency features as boron LBSF and selective emitter,

the latter respects the current restraints in production, e.g. the minimum width of screen-printed contacts.

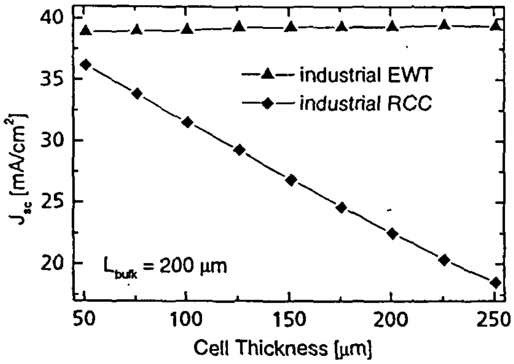

Fig. 2: EWT and RCC short-circuit current dependence on cell thickness [5]

By these two simulation schemes one can determine if the EWT cell is also interesting for production by more conventional methods or if the production steps have to be changed in order to get better efficiencies than with current cell types.

In Fig. 2 simulations of J_{sc} for industrial cells are plotted versus the cell thickness W. L_{bulk} is 200 µm. As can be seen clearly, the J_{sc} of the RCC is strongly dependent on W whereas the EWT shows a nearly constant current even for $L_{bulk}/W < 1$. The electrons collected by the RCC's floating emitter must be reinjected into the base to reach the n-grid on the backside so that a very high L_{bulk} is needed to collect all carriers. As can be seen in the graph, even for a cell thickness of 50 µm which means that L_{bulk} is four times the cell thickness, the RCC does not reach the current of the EWT cell.

The impact of this striking difference in the quality of current collection can be seen in Fig. 3. The cell efficiency has been calculated this time for „high-η" cells versus L_{bulk}. Three different cell types have been simulated: RCC and EWT with good ($S=10^3$ cm/s) and without ($S=10^6$ cm/s) surface passivation in the via holes. As for J_{sc}, the RCC efficiency rapidly decreases for decreasing L_{bulk} while the EWT is less sensible on lower L_{bulk}. Even for high quality material with bulk diffusion length above 1 mm, the EWT is still more efficient except without surface passivation in the holes.

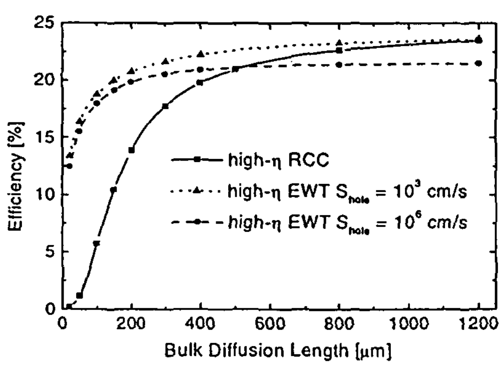

Fig. 3: EWT and RCC efficiency as a function of bulk diffusion length (W=250 µm) [5]

This difference between RCC and EWT is striking considering that at $L_{bulk}=W/2$ the EWT efficiency still is about 20% while the RCC is already reduced below 10%.

4 REALIZED EWT VARIANTS

We fabricated three variants of RCC and EWT cells in the cleanroom at Fraunhofer ISE, see Fig. 4 for upside down sketches.

4.1 Basic process

As shown in Fig. 4, upper part, our basic scheme is a bifacial type since front and back side are covered by a random pyramids texture. The base grid is buried and the emitter is comparatively highly doped (about 70 Ω/□) to ensure that the entire current from the front emitter can reach the grid on the back side.

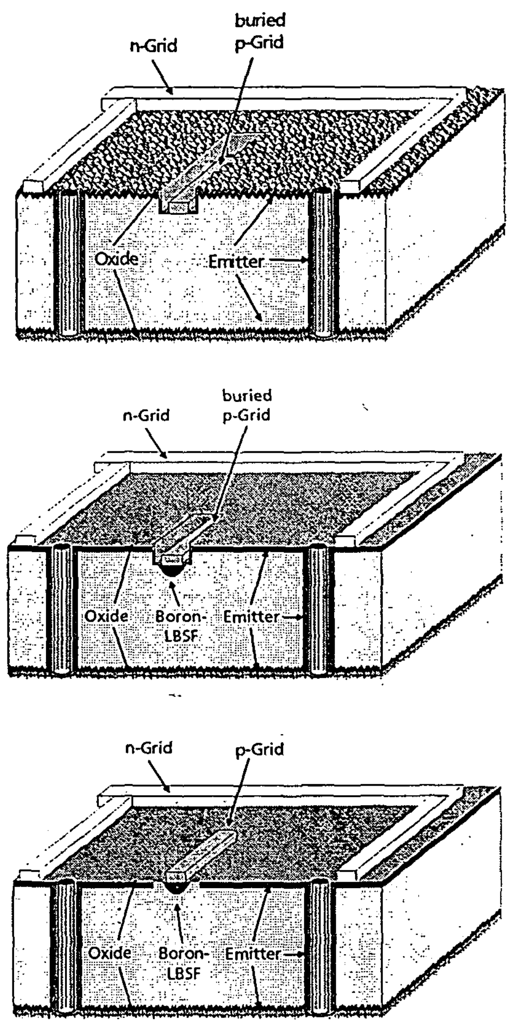

Fig. 4: Realized EWT variants. Top: basic process, middle: BBC high-η, bottom: high-η

4.2 Buried base contacts high-η (BBC high-η)

The BBC high-η variant – cf. Fig. 4 middle – uses a standard 120 Ω/□ emitter in order to reduce Auger recombination losses. The back side is flat to ease photolithographic alignment. There is also a boron local back surface field to reduce contact resistance at the base grid.

4.3 High-η process

In the high-η process (shown in Fig. 4 bottom), the grid design as well as the via-hole density have been adapted according to experiences made with the BBC high-η variant. Also, the buried base contacts concept has been abandoned for photolithographic reasons.

5 RESULTS AND DISCUSSION

A summary of the measured cell parameters of the different realized RCC/EWT variants is given in table I.

Concerning the basic process EWT cells, it is exciting that such a high J_{sc} of about 41 mA/cm² can be reached and that this value is the same for FZ- and Cz-Si (fully degraded at about L_{bulk}=190 µm and W=235 µm) wafers. V_{oc} is quite low because of the highly doped emitter but the main efficiency limitation is the fill factor that was well below 70%. This results from technological problems with the contact formation

The BBC high-η cells showed promising voltages of 687 mV (on reference 0.5 Ω cm FZ wafers) because of the lower doped 120 Ω/□ emitter. These high values indicate that the passivation of the inner hole surfaces was very successfull. Again, the efficiencies were not satisfying because of the low fill-factor due to technical problems with the metallization. The best results were obtained on Cz material (0.8 Ω cm with $L_{bulk,d}$=190 µm and W=235 µm) with a high EWT vs. RCC difference in J_{sc} of 4.6 mA/cm².

The fact that J_{sc} of the BBC high-η variant is lower than for the basic process indicates that the emitter sheet resistance limits the current flow through the via holes. As already mentioned, we modified the grid design and the hole density in order to cope with this issue. This led to the high-η variant, which could not be finished in the cleanroom of Fraunhofer ISE before the move of the laboratory to the new building.

6 EWT PERFORMANCE ON DEGRADING CZ MATERIAL

In order to represent the advantages of the EWT concept over RCC it is necessary to clarify what cell parameters one can expect for a given bulk diffusion length. While it is easy in simulations to vary L_{bulk} over a broad range, one can hardly process as many wafers with different values of L_{bulk} to validate the simulations. For this reason, we utilized the metastable defect in boron-doped Cz-Si [10] to get the information about a range of L_{bulk} with one single wafer: First, we chose a Cz wafer with RCC and EWT cells (basic process) and annealed the defect completely at 425°C for 25 minutes. Then we measured the illuminated IV-curve several times while exposing the wafer to the sun-simulator. Therefore, the metastable defect got activated

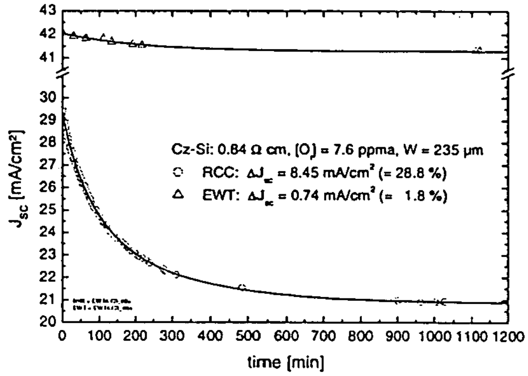

Fig. 5: Current decay of EWT and RCC on Cz(B) from annealed (t=0) to fully degraded state (t>1000 min).

more and more during the measurement, thus reducing L_{bulk} further and further. The logged J_{sc} of the RCC and EWT is shown in Fig. 5 (please note the broken J_{sc}-axis). While the current of the EWT cell is nearly stable – even at the fully degraded state the relative current loss is below 2% - the RCC loses exponentially 28.8% of its current, ending at about the half of the EWT current.

To validate our simulations, we had to transform the x-axis from time to L_{bulk}. This was possible by characterising the material through many photoconductance decay (PCD) lifetime measurements at different degradation states

Table I: Experimental results for different RCC/EWT cells (area: 6.23 cm²) processed on the same wafer.

Variant	Material	V_{oc} [mV]*	J_{sc} [mA/cm²] before (after) degradation	FF [%]*	η_{front} (η_{back}) [%]*	Cell
Basic						
EWT	1 Ω cm FZ W=235 µm	623	**41.4**	60.9	15.7 (15.4)	EWT5, 1F1.02b
RCC		614	**34.9**	52.0	11.1 (13.4)	EWT5, 1F1.03b
EWT	0.8 Ω cm Cz(B) W=235 µm	609	**40.9 (40.1)**	65.5	16.3 (16.7)	EWT6, C3.01a
RCC		612	**29.7 (22.0)**	72.5	13.2 (14.6)	EWT6, C3.02a
BBC high-η						
EWT	0.8 Ω cm Cz(B) W=235 µm	662	**39.0**	63.4	16.3 (16.5)	EWT9, C6.01a
RCC		674	**34.4**	73.7	17.1 (17.2)	EWT9, C6.02a

*: measured before degradation

resulting in an τ(t) graph. The result of this transformation is shown in Fig. 6. As can be seen, the measured current values (symbols) match perfectly our simulations (lines). By this technique, the influence of L_{bulk} on the realized cell structure can be observed very elegantly by one single wafer and proves the superior characteristics of the EWT concept.

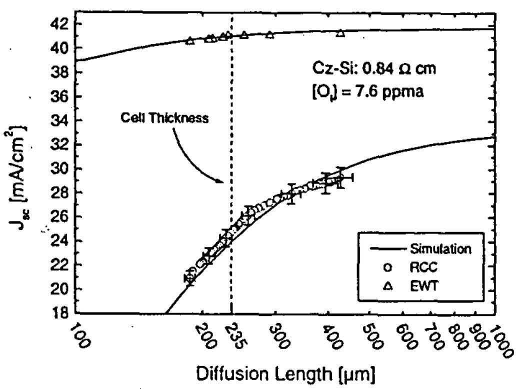

Fig. 6: Current dependance of EWT and RCC on Cz(B) upon bulk diffusion length on one single wafer.

7 CONCLUSION

We have demonstrated in this article that the emitter-wrap-through cell concept is very suitable for lower quality material even with bulk diffusion lengths below the cell thickness. The direct competitor, the rear contacted cell, is easier to process since it lacks the EWT via holes but it can only compete with the EWT for very high bulk diffusion length i.e. high quality material.

At Fraunhofer ISE, EWT cells were fabricated with a quite simple process scheme that showed short circuit currents of about 41 mA/cm^2 even on degraded Cz(B) Si (L_{bulk} =190 µm, W=235 µm). Efficiencies for the basic and BBC high-η processes were not optimum because of metallization problems.

The metastable defect in boron-doped Cz-Si can be used to measure the influence of L_{bulk} on the cell parameters by just processing one Cz(B) wafer and measuring the illuminated IV-curve at different degradation states. This is a very fast and elegant way to determine the efficiency one can expect if applying the EWT concept on a material with given L_{bulk}. This procedure has been realized on a well characterized material so that a plot of J_{sc} versus L_{bulk} could validate the 2D simulations that preceeded the cell production.

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